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PATENT SPECIFICATION

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(54) A ROTARY ELECTRIC MACHINE

(71) We, GANZ VILLAMOSSAGI MÜVEK of Lövöhaz u. 39, 1024 Budapest, Hungary, a Hungarian Body Corporate, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a rotary electric machine.

The direct cooling of the rotor winding supplied with direct current of the rotary electric machines of very high power (several-hundred megawatts) and high speed, especially the two-pole synchronous machines provided with cylindrical rotor (turbogenerators) is ensured by gas cooling or liquid cooling.

With higher powers, the gas cooling is generally realized by the use of hydrogen. The advantages of hydrogen (low specific weight, low gas frictional loss, relatively high specific heat, good electric insulating capacity, etc.) are well known.

The designers striving after the development of machines of even higher unit power can have the choice of two basic types of the direct conductor cooling, i.e. of the liquid cooling and the gas cooling. The choice is not at all simple. For the gas cooling it is to be said that this solution has traditions of several decades both with the manufacturers and the consumers, it is however, doubtful whether the intensity of gas cooling can be increased to such an extent as required by the increasing demands. For the other alternative it is to be said that the liquid has a very high specific heat and thermal conductivity, in order to enforce these advantages, however, numerous new structural, engineering and operational safety problems must be solved (increasing the number of parallel liquid paths, sealing of the cooling system etc.).

Nowadays when the increase from 500—1000 MW to 1000—2000 MW of the unit power of two-pole turbogenerators is aimed at, the question again arises whether the relative cooling technical tasks can be performed by further developing the classical hydrogen cooling technique.

When examining this question, it should be briefly mentioned that the most intensive forms of the hydrogen cooling used in the rotors of large turbogenerators can be also divided into two groups. The cooling gas discharges in both groups in the same manner, radially, on the outer surface of the rotor in the direction corresponding to the centrifugal force.

With the first group, the cooling gas enters the rotor axially on the endfaces of the rotor, then it flows axially either in the channels developed in the conductors themselves or in the iron body of the rotor in the subslots developed beneath the coil slots, then it turns in radial direction and leaves the rotor on contacting the coils. In this case, the axial direction is characteristic to the flow of the cooling gas, therefore these systems will be called "axial" systems.

With the second group, in case of rotors of so-called "gap pick up" system, the cooling gas enters the rotor from the outer surface and flows inwards in radial direction, then flowing in axial or tangential direction, or having such direction-components it contacts the conductors to be cooled, finally turning again in radial direction it leaves the rotor. With the system being called the "gap pick up" system, the radial flow is characteristic.

The usefulness of hydrogen-cooled rotors depends to a significant extent on the gas quantity to be introduced into the rotor in unit time.

The gas quantity to be carried into the rotor is—as experience shows—approximately proportional to

D^2 in case of "axial" system and

(D.L.) in case of "gap pick up" system

(D—diameter of the rotor, L—active iron length). Consequently, the rotor of "axial" system shall be made with a short iron body and with a diameter as large as possible, whereas in case of a "gap pick up" system, the gas quantity to be introduced increases proportional to the iron length. While thus the length of the rotor of axial flow is limited (the flow losses increase together with the increase of the length of flow channel, the in-

take cross-section on the front side is relatively small), with the "gap pick up" system the relatively small cross-section of the inlet and utlet ports developed generally in the coil fastening keys, n the uter surface of the rotor limits the quantity of cooling gas to be passed through the rotor.

After all, the utilizability of the rotor is limited with the known solution of "axial" system and of "gap pick up" system, since also the gas quantity to be introduced is limited. With the known methods, the maximum unit capacity to be achieved at the two-pole turbo-generator amounts to about 1000—1200 MW at the largest rotor diameter admissible with respect to the strength (about 1250 mm).

With the "axial" system—as already mentioned—the length of the iron body is limited, since an advantageous "axial" cooling can be achieved with proportions of at most L=3∼4 D. The diameter of the rotor, however, cannot be increased beyond a certain limit for strength reasons, therefore the gas quantity to be introduced can be increased only when increasing the length of the iron body. The length of the iron body of the machine of required very high power should be at least L=6∼8 D, a rotor of such a length, however, cannot be efficiently cooled with an "axial" cooling system.

The basis of the "gap pick up" system is that between the inlet and outlet ports on the outer surface of the rotor, a constant differential pressure occurs as a result of the rotation (dynamic pressure and suction), rendering possible the introduction of the cooling gas into the rotor. Since the centrifugal force produces theoretically the same effect both in the inlet and in the outlet channels, these two effects should compensate each other according to the principle of continuity. In the practice, however, the gas entering the rotor is considerably colder and consequently of higher density than the gas discharging from the rotor. Thus, a greater centrifugal force is operative on the gas in the inlet channel than in the outlet channel. This phenomenon impairs the intensity of cooling and to the greater extent the greater the difference between the temperature of the inlet gas and that of the outlet gas and the deeper the coil slot it.

As it is to be seen, a proper cooling can be achieved with the known "axial" and "gap pick up" systems only in case of machines of specified dimension (power), with the former system the length of the slot (iron body), with the latter one the depth of the slot is limited.

The aim of the invention is the development of electric rotary machines, especially for high-power and high-speed synchronous machines provided with cylindrical rotor, by means of which machines of larger dimensions (power) than those used up to now can be effectively cooled and which renders unnecessary the change-over to the liquid cooling with machines of 1000—2000 MW power.

According to the present invention there is provided a rotary electric machine, comprising a cylindrical rotor in which coil slots receive conductors of a rotor winding, an extension region formed below each of the coil slots not receiving the conductors of the rotor winding, cooling channels lying in planes having their normals substantially perpendicular to the rotor axis and formed in or between the conductors of the rotor winding, adjacent cooling channels being connected to each other and the cooling channel nearest to the rotor axis being connected to the extension region, and the cooling channel farthest from the axis being connected to inlet and outlet ports leading to an airgap surrounding the rotor of the rotary electric machine and displaced from each other in the axial direction.

The main advantage of the solution according to the invention is that the cooling of "gap pick up" system of the conductors farther from the shaft is effected at a relatively low counterpressure and the gas quantity necessary for the cooling according to the "axial" system of the conductors nearer to the shaft can be introduced without difficulty.

The invention will no\ .e described in more detail, by way of example only, with reference to the accompanying drawings, in which:—

Figure 1 is the section taken in a plane perpendicular to the shaft, of the rotor of a synchronous machine provided with cylindrical rotor, using cooling channels of tangential direction,

Figure 2 shows the gradual section II—II of the rotor according to Figure 1,

Figure 3 is the section taken in a plane vertical to the shaft, of the rotor of a synchronous machine provided with cylindrical rotor, using cooling channels of axial direction, and,

Figure 4 shows the gradual section IV—IV of the rotor according to Figure 3.

In case of the embodiment according to Figures 1 and 2, coil slots 2 are developed in the iron core 1 of the rotor of the synchronous machine provided with a cylindrical rotor. Beneath the coil slots 2 are provided subslots 3. A winding consisting of outer 8 and inner 9 conductors is arranged in the coil slots 2. The conductors 8, 9 are arranged in the coil slots 2 parallel to each other in axial direction. Adjacent turns of the winding are separated from each other by means of insulators 17. Insulators 7 are arranged along the side walls of the coil slots 2 and insulators 5 and 6 are arranged respectively at the top and bottom of the coil slots 2. Channels 10, 11 are formed in

the radial direction in the insulators 7 and communicate with cooling channels 14, 15 formed in the conductors 8, 9. The channels 14, 15 lie in the tangential direction perpendicular to the rotor axis. Through the inner conductors 9, in the symmetry plane of the coil slot 2, inlet channels 16 (marked with dashed line in Figure 2) are provided interconnecting the subslot 3 with the cooling channels 15. The mouth of the coil slot 2 is closed by a wedge 4 in which inlet 12 ports and outlet ports 13 are provided. The ports 12, 13 are inclined as compared to the radial direction, in such a manner that the inlet ports 12 are slanted in the rotation sense, whereas the outlet ports 13 are opposite to the rotation sense.

The flow direction of cooling gas is indicated by arrows in Figures 1 and 2. Accordingly, the cooling gas enters the coil slot 2 through the subslot 3 and the inlet ports 12. From the inlet ports 12 the cooling gas flows into the channels 10 along one wall of the coil slot then into the cooling channels 14, thereafter into the channel 11 along the other wall of the coil slot and finally flows out from the rotor through the outlet ports 13 into the airgap of the synchronous machine. From the sub-slot 3 the cooling gas flows through the inlet channels 16 into the cooling channels 15, therefrom directly, and through the channels 10 along one side wall of the coil slot as well as through the cooling channels 14, respectively into the channels 11 along the other wall of the coil slot, finally through the outlet ports 13 into the airgap of the synchronous machine.

It can be seen that the cooling of the outer conductors 8 is performed according to the "gap pick up" system, that of the inner conductors 9 according to the "axial" system.

In case of an embodiment according to Figures 1 and 2, a special advantage is ensured by that the cross-section of the channels 10, 11 of radial direction—the coil slot 2 being trapezoidal—increases to the same extent as the gas quantity passing it.

In case of the embodiment according to Figures 3 and 4, no cooling channel is provided along the side walls of the coil slot 2 and the cooling channels 14, 15 between the conductors 8, 9 lie along the axial direction. The cooling channels 14, 15 run axially through the conductors 8, 9. The interconnection between the subslot 3 and the inner conductors 9 is ensured by inlet channels 16, like with the former example, of which, however, only every second one lead directly into the subslot 3, the others reach only up to the innermost cooling channel 15 and are connected through that with the subslot 3. The connection between the cooling channels 14 of the outer conductors 8 and the inlet 12 and outlet 13 ports is ensured by channels 18, 19 developed similarly to the channels 16 and laying in line therewith. They are alternately connected with the ports 12 and 13, namely in such a manner that the channel 19 connected to the port 13 is also directly connected to the channel 16 developed in line therewith, while the channel 18 connected to the port 12 is separated from the channel 16 laying in line therewith at the point "A".

The flow direction of the cooling gas is indicated by arrows also in Figures 3 and 4. The cooling gas flows from the subslot 3 into the channels 16 open at the bottom then through the cooling channels 15 towards the adjacent radial channels 16. These latters are interconnected with the channels 19, through which the cooling gas flows into the outlet ports 13 and therefrom into the airgap. The cooling gas entering through the inlet ports 12 flows into the channels 18, then—through the cooling channels 14—into the adjacent channels 19 and therefrom, through the outlet ports 13 again into the airgap. The cooling of the outer conductors 8 takes place according to the "gap pick up" system, that of the inner conductors 9 according to the "axial" system. Since the channels 16 and 18 are separated from each other, the cooling system of the outer conductors 8 and that of the inner conductors 9 are practically fully independent of each other and the cooling gases flowing in the two systems are mixed with each other only at the discharge.

How many of the conductors laying in the slot are connected in the "gap pick up" cooling system and how many in the "axial" cooling system, depend always on the given special conditions. If a half-and-half ratio is taken, it is obvious that the cooling of "gap pick up" system will be considerably more intensive as compared to the case when all conductors would be cooled in the "gap pick up" system, since the available cooling gas quantity is practically constant, the heat to be taken away reduces to the half. Accordingly, the warming up of the cooling gas and the density difference of the inlet and outlet cooling gas are also reduced to the half. Due to the reduction to the half of the density difference as well as of the thickness of layer to be cooled the counterpressure impeding the flow of cooling gas is reduced as well.

If the "axial" cooling is applied only on the lower 1/3—1/4 part of the complete coil height, the gas quantity bowing from the part of "axial" system to the common output channel will be even in this case advantageous, reducing also the above mentioned density difference. Moreover, with the embodiment according to Figures 1 and 2 a less quantity of hot cooling gas flows from the part of "axial" system into the inlet channel of the part of "gap pick up" system, than in the case when the complete coil slot is cooled according to the "gap pick up" system.

In a rotary electric machine in accordance

with the invention a current density of 15—20 A/sq.mm at an overpressure of about 5 atmospheres in the coil turns may be achieved using hydrogen as a cooling gas. Thus, turbo-generators of unit capacity even above 1000 MW can be produced.

WHAT WE CLAIM IS:—

1. A rotary electric machine, comprising a cylindrical rotor in which coil slots receive conductors of a rotor winding, an extension region formed below each of the coil slots not receiving the conductors of the rotor winding, cooling channels lying in planes having their normals substantially perpendicular to the rotor axis, and formed in or between the conductors of the rotor winding, adjacent cooling channels being connected to each other and the cooling channel nearest to the rotor axis being connected to the extension region, and the cooling channel farthest from the axis being connected to inlet and outlet ports leading to an airgap surrounding the rotor of the rotary electric machine and displaced from each other in the axial direction.

2. A rotary electric machine as claimed in claim 1, wherein the cooling channels lie along tangential axes perpendicular to the rotor axis.

3. A rotary electric machine as claimed in claim 2, wherein the cooling channel nearest to the shaft is connected to the extension region through channels of radial direction arranged in the centreline of the coil slot, and the cooling channel farthest from the shaft is connected to the inlet and outlet ports through chambers of radial direction arranged along the side walls of the coil slots.

4. A rotary electric machine as claimed in claim 3, wherein the chambers of radial direction arranged along the side walls of the coil slot extend from the cooling channel farthest from the shaft to the cooling channel nearest to the shaft and the chambers of radial direction connected with the extension region extend at least to the cooling channel which is the second nearest to the shaft.

5. A rotary electric machine as claimed in claim 1, wherein the cooling channels lie along axes parallel to the rotor axis.

6. A rotary electric machine as claimed in claim 5, wherein the cooling channel nearest to the shaft is connected to the extension region, and the cooling channel farthest from the shaft is connected to the inlet and outlet ports through channels of radial direction arranged in the centreline of the coil slot.

7. A rotary electric machine as claimed in claim 6, wherein of the radial channels connected to the cooling channel nearest to the shaft, only those in line with the radial channels connected to the inlet ports are connected to the extension region.

8. A rotary electric machine as claimed in claim 7, wherein the radial channels connected to the outlet ports extend to the cooling channel nearest to the shaft.

9. A rotary electric machine as claimed in claim 7, wherein the inlet channels of radial direction connected to the extension region extend at least to the cooling channel which is the second nearest to the rotor axis and the remaining cooling channels to which the inlet channels are not directly connected are connected to the outlet ports.

10. A rotary electric machine as claimed in claim 1, wherein the inlet ports are inclined in the direction of rotation of the rotor, and the outlet ports are inclined in the opposite direction.

11. A rotary electric machine substantially as herein described with reference to the accompanying drawings.

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1456068 COMPLETE SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

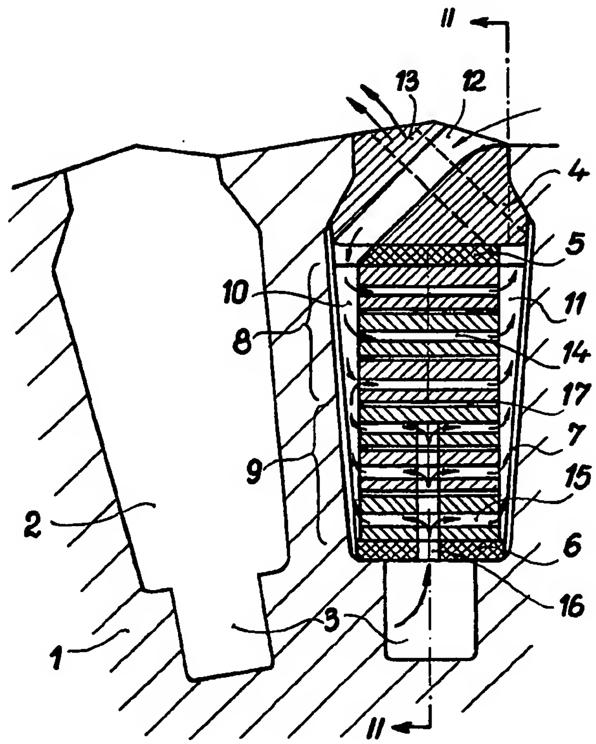

Fig. 1

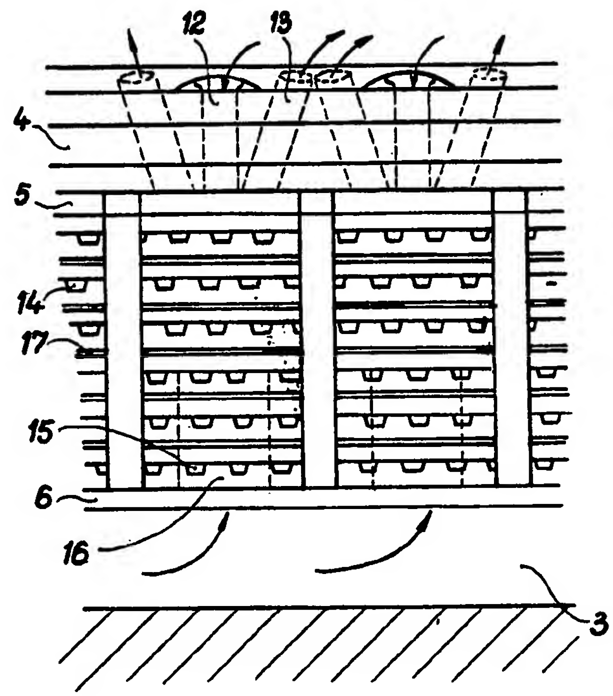

Fig. 2

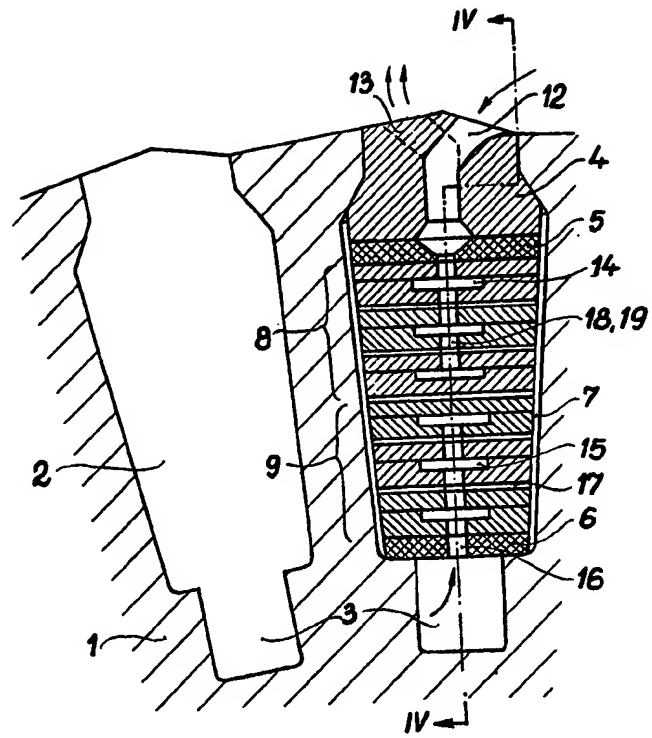

Fig. 3

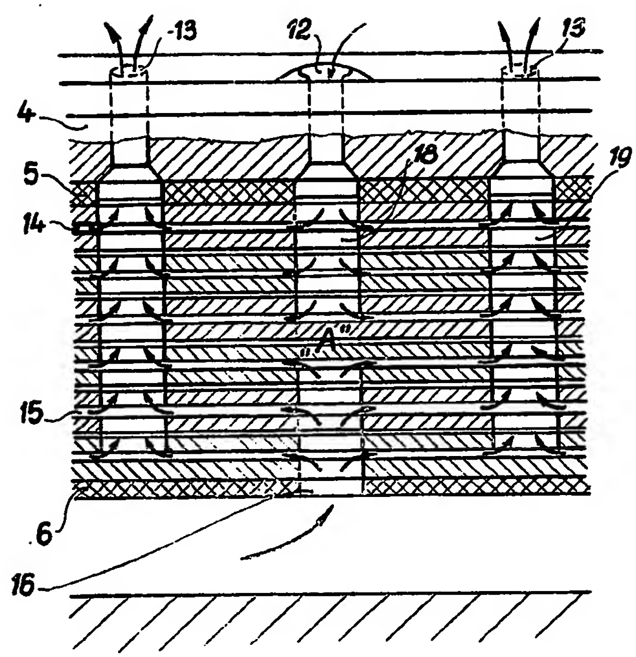

Fig. 4